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A visionary and conceptual macroalgae-based third-generation bioethanol (TGB) biorefinery in Sabah, Malaysia as an underlay for renewable and sustainable development

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ABSTRACT

Several biofuel candidates were proposed to displace fossil fuels in order to eliminate the vulnerability of energy sector. Biodiesel and bioethanol produced from terrestrial plants have attracted the attention of the world as potential substitute. However, due to food vs. fuel competition as well as land consumption of these biofuel, they have brought much controversy and debate on their sustainability. In this respect, cultivation of macroalgae such as seaweed at sea water which does not expend arable land and fertilizers provides a possible solution for this energy issue. Carbohydrates derived from seaweeds contain hexose sugars which are suitable materials for fermentation to produce ethanol. Therefore, it is possible to produce fuel ethanol from seaweeds. The potential and prospective of seaweeds to play the role as a sustainable energy provider are demonstrated in this paper. This study offers a conceivable picture of macroalgae-based third-generation bioethanol biorefinery to stimulate the initiation of the exploration in the related field.

Contents

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1. Introduction

Since people learned that utilizing renewable resources was essential for sustainable development, energy policies had slowly shifted to renewable resources such as biofuel. In particular, liquid biofuel has become the priority since 40% of total energy consumption in the world is in the form of liquid fuels [1]. An upward trend is shown in global liquid biofuel production from 4.8 billion gallons in 2000 to about 16.0 billion in 2007 [2]. Technologies are then peppered with the exploitation of crops which have high energetic values such as edible oil and sugarcane to produce biodiesel and bioethanol, respectively. While development of fuels from biomass continues apace, first generation biofuel based on edible crops has raised morality and ethics issues as there are millions of people around the world still suffer from malnutrition and hunger. In order to overcome this issue, bioethanol refined from lignocellulosic biomass, namely second-generation bioethanol (SGB) offers a great option which is compatible with economic growth and morality issues [3]. However, although SGB is attractive with its non-edible feedstock, it is much debated because the cultivation of terrestrial plants requires the resources that could otherwise be used for food. Furthermore, separation of lignin content from lignocelluloses has become an obstacle to be combated. In this context, third-generation biofuel based on marine algae and seaweeds offers an excellent alternative to displace fossil fuels. The ancestors of marine microorganism exist even before the formation of petroleum. Similar to all living organism on earth, the sun provides energy for algae and seaweeds to grow. Through a couple of billion years of evolution, algae have developed an efficient system to capture limitless solar energy continuously via photosynthesis [4]. At higher photosynthetic efficiencies relative to terrestrial biofuel feedstock, carbon dioxide is absorbed from the atmosphere and hydrogen is separated from the water to build up the carbohydrates which have only one oxygen atom on each carbon atom [5]. With a proportion of the solar energy trapped in their chemical bonds [6], carbohydrates can be further refined to produce bioenergy carriers such as bioethanol. Thus, cultivation and engineering of marine algae have drawn the world's attention in advancing the ability of algae to become a substitute for petroleum. Since algae are cultured on non-arable land, there is no misgiving on fuel-food feud [7]. Coastal area is favored as algae cultivation site due to the rich content of soluble nitrogenous compounds released from sediment during the decomposition of organic matter. Macroalgae, namely seaweeds, can be cultivated by tying them to anchored floating lines at sea. Therefore, algal cultivation is not limited by agricultural expansion over terrestrial plants. On the other hand, the growth rate of algae is tremendously high relative to land cultivation crops. In other words, there is a promising supply of biomass with only simple inputs: sea water, sunlight and carbon dioxide. In fact, the utilization of sea water greatly prevents fresh water crisis. From the point of view of ecology, macroalgae assist in reducing carbon dioxide in the atmosphere and supplying oxygen to the sea. In addition, some seaweeds species are known for their ability to remove heavy metals from the water which can be very beneficial to the environment [8]. Algae are also well-known of their capability to withstand harsh conditions and survive in stressed environment.

Third-generation bioethanol (TGB) represents fuel ethanol produced from algal biomass. Generally, ethanol is mainly produced from enzymatic fermentation of mono-sugars such as glucose. Certain species of algae have the ability to produce high levels of carbohydrates instead of lipids as reserve polymers. These species are ideal candidates for the production of bioethanol as carbohydrates from algae can be extracted to produce fermentable sugars. Seambiotic, in collaboration with Inventure Chemicals, successfully demonstrate the production of bioethanol by fermentation of the algal polysaccharides. In their plant, algae were cultivated in fossil-fuel power plants to absorb CO_2 emitted as source of inorganic carbon [9]. Apart from that, instead of extraction, there are also algal species able to conduct self-fermentation. Ueno et al. [47] reported that dark fermentation in the marine green algae *Chlorococcum littorale* was able to produce 450 μmol/g-dry wt. ethanol at 30 °C. Algenol Biofuels Inc. claims that its plant is able to produce ethanol at a rate of over 6000 gallons per acre per year. They stressed on the tolerance of the engineered algae on high heat, high salinity, and the alcohol levels present in ethanol production [10]. It is believed that discoveries of ways to exert the algal resources, both macro and micro-types of algae would ignite a remarkable energy revolution in the future.

With increase of food supply results from advancement in agriculture sector, Malaysia's population had risen sharply in an unstoppable momentum, escalating to a new height of 27.17 million in the year 2007 [11]. At the same time, the energy demand is rising exponentially to 44,268 ktonnes in 2007 with the soaring surge of population [12]. Around 35.5% of the demand comes from transportation sector which mostly utilizing liquid fuels. Therefore, third-generation bioethanol (TGB) which is carbon 'neutral' and essentially free from sulphur and aromatics can become one of the most suitable candidates for displacing petroleum-derived fuels in Malaysia and also the world. With only carbon dioxide and water released from combustion of TGB, Malaysian would be able to enjoy a cleaner environment.

Until recently, there are numerous studies focuses on production of biodiesel from microalgae [13] but still lack of research on production of bioethanol from seaweeds. Macroalgae in fact contain high amount of carbohydrates which can be utilized for the production of bioethanol. Thus, the aim of this study is to highlight the possibility, perspective and challenges of production of TGB from seaweeds in Malaysia. In this work, Sabah state was proposed as the location for the production TGB. In the first part, potential and advantages of conversion of seaweeds into TGB is briefly discussed. Next, site selection in the state was discussed for cultivation and refining of seaweeds. Subsequently, the concept of algal biorefinery was elucidated. This paper also discusses the national and state policies on renewable energy and seaweed cultivation. Finally challenges and constraints in developing TGB industry in Malaysia are elaborated.

2. Seaweeds for bioethanol production: *Euchema* spp.

2.1. Seaweeds availability in Sabah

Sabah embraces numerous species of seaweeds. Among these species, *Euchema* spp. is one of the most abundant species along the coastal area. Eucheumata is a multiaxial filamentous red algal genus with thalli weighed up to a kilogram. They have high vegetative regenerative capacities and grow very fast. They are found from just below the low tide mark to the upper subtidal zone of the reef in slow or moderate water movement. These endemic seaweeds require sandy-corally or rocky substrata to grow. At the tip of the branches, there is a group of apical meristem cells which divide actively. It is best to describe the life cycle of *Euchema* spp. as a triphasic one. They transform from gametophyte (n) (dioecious) to carposporophyte (2n) and finally the sporophyte (2n) [14]. The most important component of seaweed, in terms of industrial use, is a substance called carrageenan also commonly known as seaweed flour. The seaweeds cultivation industry is growing fast in the recent years, from less than 5000 tonnes in the year 1985 to more than 110,000 tonnes in the year 2005. The main producers are the Philippines, China, Indonesia, Malaysia (Sabah), Tanzania and Kiribati [14].

Fig. 1. Location of Sabah, Malaysia.

2.2. Chemical composition of seaweeds

Tong et al. [15] reported that species from Eucheumata found growing abundantly in Singapore water contains mainly carbohydrates, accounting for over 70% of the dry weight. The polysaccharides exist in *Eucheuma* spp. are largely in the form of carrageenan as cell wall component. Carrageenan is a linear, sulphated polysaccharide, the primary structure being made up of alternating α(1-3)-D-galactose-4-sulphate and β(1,4)-3,6-anhydro-D-galactose residues [16]. Other than carrageenan, small amount of cellulose is also detected in the biomass. The content of carbohydrates of *Eucheuma* spp. was investigated to be 56.2% of D-galactose and 43.8% of 3,6-anhydro-galactose [17].

2.3. Sustainability of macroalgae-based third-generation bioethanol (TGB)

Production of bioethanol from seaweeds is considered a new idea which can be evaluated in terms of sustainability and environmental conservation. Similar to other biofuel, TGB is produced from biomass, which means it is carbon neutral and renewable. However, cultivation of seaweeds does not need soil and arable land. Seaweeds live in saline seawater and grow hydroponically. In other words, cultivation of seaweeds does not compete for resources with conventional agriculture. This makes a huge difference with other terrestrial crops which in fact exploit natural resources such as soil and fresh water. The feasibility of terrestrial crops-based biofuel is largely depended on land availability [18]. Large area of land is required for cultivation of energy crops with secondary effects such as alteration of forest ecosystem and land contamination [19,20]. In some countries, fertile soil and fresh water are scarce resources with part of the reasons is due to climate changing.

On the other hand, production of biofuel from seaweeds cultivation on seawater is a potential new approach since 70% of earth surface is covered by water rather than land. Seaweeds have different life cycle from terrestrial plants. They are more productive than other crops as more than five harvests can be obtained in a year. In addition, seaweeds thrive in salty water with merely sunlight and some simple nutrients from seawater. They do not need any chemical fertilizers. Large amount of energy, exergy and money is saved from fertilization. This characteristic improves the sustainability of macroalgae-based TGB. On the other hand, production of first generation bioethanol from terrestrial plant contributes large environmental impact to human and ecotoxicity, acidification and eutrophication. This is mainly caused by the agricultural process, especially generation of waste water from plantation [21]. In general, seaweeds can be adapted to live in a variety of environmental conditions. There is wide range of seaweeds which grow along the coastal area in the world. The simplicity in genetic information makes it viable for adaption. With advance genetic engineering, it is not impossible to engineer a better species of seaweeds for TGB production. These features engender high optimism for future development of seaweeds in renewable energy sector such as bioethanol.

3. Production of TGB in Sabah

3.1. Site availability

3.1.1. Key characteristics of Sabah

Sabah consists of a great number of islands as well as coral reefs, including the largest island in Malaysia, Pulau Banggi. The state is situated approximately between latitude 4–7°N and longitude 115–120°E, at north-east part of Borneo island, as illustrated in Fig. 1. The state of Sabah consists of five divisions; namely, Tawau, Sandakan, Kudat, West Coast and Interior. As the second largest state among the 13 states of Malaysia, the state has a total land area of 73,600 km^2. Sabah is bestowed with a coastline of approximately 1600 km, surrounded by Sulu Sea at the east coast and South China Sea at the west coast [22].

Similar to other states on Peninsular, Sabah has a tropical climate with an average mean daily temperature of about 27 °C. The mean daily maximum and minimum temperature range between 31.9 and 23.5 °C, respectively. The state has high mean humidity which varies between 66% and 75%. The average annual rainfall is about 2908.7 mm. The rainfall is high especially during rainy seasons from April to October (southwest monsoons) and from October to February (north-east monsoons) [23].

The state is located at the center of the world's highest marine biodiversity ecosystems. The water contains abundant and diverse marine resources, which include coral reefs, fisheries and coastal wetlands. The sea water depth can be as deep as over 2000 m [24]. Movement of surface water is generally driven by wind. On average, surface sea temperature for the water bodies around Sabah is about 30 °C [25]. The surface salinity of the water body is rather consistent at a value of 34 ppt [26]. The sea water near shore has an average pH of 7.5 and dissolved oxygen of 77.6%. The water current has a speed range between 0.09 and 0.81 m s^{-1}. Suspended solid concentration recorded a value of 0.12 g/L on average [27].

Although the state of Sabah, which is located in the middle of one of the 12 mega-diversity sites in the world, with numerous and varied natural resources, it is the poorest state in Malaysia, with 23% of household living below poverty line recorded in the year of 2004 [28]. The population of this state is approximately 3 million, with majority concentrated at Kota Kinabalu, Tawau and Sandakan [29].

3.1.2. Cultivation sites

The selection of site largely depends on the geological and ecological factors. A detail analysis of exposure, water depth,

pollution risk, accessibility and potential environmental impacts on coral reefs are important during selection. Near shore areas are more suitable to be chosen for farming to prevent competition with fishing activities. River mouths and places of runoff are avoided because these locations may affect salinity and extend exposure at low tide. Rock shores and reefs are favored for endemic seaweed species. Good water movement is also an important factor in site selection. Rapid water turnover is preferred but not heavy enough to damage the farm [30].

Sabah is the only state in Malaysia which is currently involve in seaweed farming. Semporna, Kunak and Lahad Datu are the main locations for seaweed cultivation in Sabah. A preliminary survey of the potential areas of Sabah's coasts revealed that more than 100,000 ha of sea are suitable for this type of aquafarming. According to a Geographic Information Systems (GIS) analysis carried out by the Fisheries Department, the northern and south-eastern parts of Sabah which is surrounded by sea water from Sulu Sea are potentially more suitable than the western part for seaweed culture. Semporna has become the focus point since it provides 84,330 ha of suitable seaweed cultivation area. The government plans to expend the cultivation in Semporna up to 15,580 ha [31].

In fact, the cultivation of seaweed uses relatively low energy and financial input. In Sabah, cultivation methods employed include the traditional long line and newly introduced basket technique. By tying fragments of seaweeds to the stretched long lines, the fragments were capable of regenerating a whole new plant and ready for harvesting on a monthly basis.

3.1.3. Refining sites

The capital of Sabah state, Kota Kinabalu, is proposed as refining site. This largest city in Sabah is situated on the northwest coast of Borneo facing the South China Sea, playing the role as the main industrial and commercial center for Sabah. Other than palm oil and agriculture, fisheries and aquaculture have arisen as the third important industry in Sabah. Likas, Kolombong, and Inanam are among the important industry districts. Kota Kinabalu Industrial Park (KKIP) in Sepanggar occupies 8320 acre area has become the main hub for Brunei-Indonesia-Malaysia-Philippines East ASEAN Growth Area (BIMP-EAGA) region [32].

Kota Kinabalu is facilitated with massive transport network which linked to distant towns such as Tawau, Sandakan, Kudat, by means of highways. Besides that, there is a railway system connecting interior to the port in Kota Kinabalu for the purpose of cargo transportation and commuter service. Kota Kinabalu International Airport (KKIA), the main gateway to Sabah provides domestic and international flights. For sea transport, Kota Kinabalu has two important ports, namely Kota Kinabalu Port and Sepanggar Bay Container Port (SBCP). Kota Kinabalu Port is able to handle tonnage of 3.32 million tonnes in a year after Sandakan Port (4.83 million tonnes) [33].

3.2. Algal biorefinery concept

Conversion of polysaccharides from seaweeds to fermentable sugar and thus fuel ethanol is still yet to be studied. Although there is wide availability of seaweeds in Sabah, there are still no suggestions for the production of third-generation bioethanol from seaweeds. In this context, this study will briefly illustrate an algal biorefineries concept in order to attract the attention of researchers on the perspective of algal ethanol. Fig. 2 shows the conversion of seaweeds into TGB using algal biorefineries concept. Algal biorefineries concept is a green and zero pollution idea. Incorporating ecotourism with seaweed cultivation and refining would be a wise idea as it complies with the principle of sustainable development. It is also an alternate livelihood option for the coastal economy. Cameron Highland located at Peninsular Malaysia would be a good ecotourism example to follow.

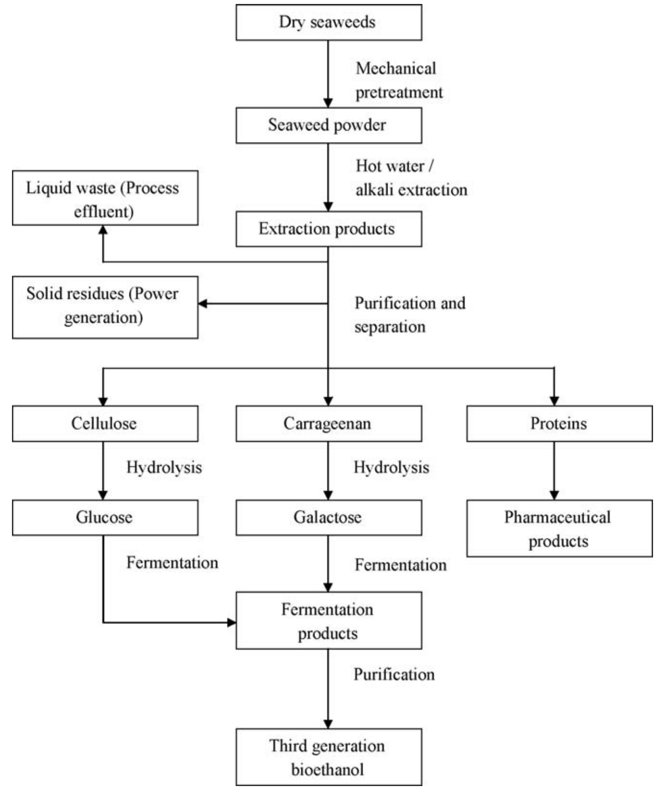

Fig. 2. Block flow diagram of conversion of seaweeds into TGB using algal biorefineries concept.

3.2.1. Collection

In Sabah, most of the commercial activities are carried out at the coastal area. There are numerous ports along the coastline provided with facilities and infrastructures. Sabah has eight international seaports: Kota Kinabalu, Sepangar Bay, Sandakan, Tawau, Lahad Datu, Kudat, Kunak and Labuan. They have the ability to handle approximately 19 million tonnes of cargo per year [33]. The collection of seaweeds can be done along the sea roads. To overcome the difficulties in transportation of hygroscopic ethanol, dry seaweeds are transported to a suitable location for ethanol production and refining.

3.2.2. Extraction and purification of polysaccharides

Since Sabah is situated in equatorial zone, drying of seaweeds can be done under the sun. Desalination has to be carried out because salinity would cause problem during purification. Several desalination technologies were studied such as solar desalination [34]. The extraction process of carrageenan is very little publicized. A good yield of carrageenan may range between 23% and 36%. The dried seaweeds will then be cooked with hot water and alkali to extract the polysaccharides. The extract will be purified through filtration and centrifugation. These processes are where the principal costs lie within. Currently, there are two options for water removal after purification: spray drying on steam-heated drums or precipitation with alcohol [35].

3.2.3. Hydrolysis

The resulting polysaccharides can be converted to fermentable sugar through enzymatic hydrolysis or mild acid hydrolysis. In mild acid hydrolysis, sulphuric acid will be added at 80 °C and heated at 100 °C for 3 h. Neutralization can be carried out with

Table 1
Annual production capacity of TGB in Semporna, Sabah.

Component	Value	Unit	Reference
Unit of cultivation	–	line	
Area of 1 unit of cultivation	5	m^2/line	
Wet seaweed yield	30	kg/line/harvest	[39]
Moisture content	90	%	
Dry seaweed yield	3	kg/line/harvest	[39]
Number of harvest	5	harvests/year	[39]
Dry seaweed production rate	3	kg/m^2/year	
Carbohydrates yield	0.7	kg/kg dry seaweed	[15]
Galactose content in carbohydrates	56.2	%	[17]
Galactose yield	0.3934	kg/kg dry seaweed	
Galactose production rate	1.18	kg/m^2/year	
Theoretical yield	51.1	%	
Fermentation efficiency	0.39	%	[37]
Area available	102,413	ha	[31]
Annual dry seaweed yield	3,072	ktonnes	
Annual galactose yield	1,209	ktonnes	
Annual TGB yield	241	ktonnes	
Net calorific value for ethanol	27	GJ/tonnes	[40]
Energy produced	6.50	$10^6 \times$ GJ	

$BaCO_3$ [17]. Currently, there are still no publicized technologies to hydrolyze carrageenan using enzymes. However, it is believed that advancing genetic engineering is capable to modify the available enzymes such as amylase to carry out the hydrolysis process.

3.2.4. Fermentation

Currently, large-scale galactose fermentation to ethanol is still not available. In fact, research on galactose fermentation is still not sufficient. Similar to glucose, galactose is a hexose sugar found in disaccharide lactose. Galactose has similar structure as glucose with just one difference in the stereochemistry of C4 carbon. However, from a GB-Analysts report, it was claimed that most of the microbes found to be effective in the fermentative oxidation of glucose substrate are also effective for the fermentative oxidation of galactose substrate [36]. *Saccharomyces cerevisiae*, one type of well-known yeast used in fermentation, is also capable of galactose fermentation. From the literature, a strain of *S. cerevisiae* was found to exhibit exceptional fermentative performance on galactose. It is able to completely exhaust the sugar in significantly less time (6 h) than that typically required by other strains tested (10–24 h). Fermentation will be performed in a bioreactor containing YP-sugar liquid media in an orbital shaker for 24–48 h at 30 °C and 125 rpm. Aliquots were centrifuged (14,000 rpm) for 4 min at 4 °C to yield cell-free supernatants, which were then decanted. By using this method, maximum ethanol product per unit substrate can be as high as 39% [37].

Thomas et al. [38] have reported galactose fermentation by the bacteria *Streptococcus lactis* and *Streptococcus cremoris* in the year 1980. *S. lactis* are adaptive fermentative metabolizer of galactose. Two biochemical pathways: the D-galactose-6-phosphate pathway, and the Leloir pathway were suggested for the metabolic reaction of converting galactose into glucose-1-phosphate. Hence the substrate will enter Entner–Deudoroff pathway, followed by fermentation reaction that produces ethanol and carbon dioxide. It was proposed that the facultative bacterium *Lactobacillus pentoaceticus* are suitable for ethanol production since it tends to preferentially produce large quantity of ethanol from galactose with only small amount of acetic acid [36].

3.3. Estimated production capacity of TGB from algal biorefinery

Cultivation of seaweeds using line method is employed in this calculation. The basic unit use to measure the cultivation is one line. Area required for one line of seaweed culture is approximately 5 m^2. Foscarini and Prakash [39] reported that each line produces 30 kg of seaweeds in one harvest. *Eucheuma* spp. needs 6–8 weeks to grow until ready to be harvested. Excluding the days with extreme weather during monsoon seasons, 5 harvests can be achieved within a year. In short, 3 kg of seaweed can be harvested from 1 m^2 of cultivation area annually.

From the literature, *Eucheuma* spp. contains 70% of carbohydrates. 56.2% of galactose can be extracted from these carbohydrates. Hence, it can be computed that 0.3934 kg of galactose can be obtained from 1 kg of seaweed, which means 1.18 kg from 1 m^2 of cultivation area annually. The area available for seaweed farming in Sabah is estimated using GIS system, and the results show that there are 102,413 ha of area has the potential [31]. In other words, 1209 ktonnes of galactose can be produced in Sabah annually. Theoretically, 1 kg of galactose yields 0.511 kg of ethanol according to Eq. (1). The fermentation efficiency is assumed to be 0.39 [37]. By using Eq. (2), the annual ethanol yield from seaweeds is estimated. The detail information is listed in Table 1.

$$C_6H_{12}O_6 \rightarrow 2CH_3CH_2OH + 2CO_2 \quad (1)$$

$$\text{Ethanolyield} = \text{Galactoseyield} \times \text{Theorecticalyield} \times \text{Fermentationefficiency} \quad (2)$$

The total amount of TGB that can be produced from these seaweeds is roughly estimated to be 241 ktonnes. The quantity will increase in the future along with improvement in extraction and fermentation of galactose. Using the known net calorific value of 27 GJ/tonnes for ethanol [40], the total energy potentially available from the TGB is 6.50×10^6 GJ. In the year 2007, the transportation sector in Sabah consumed a total amount of energy accumulating to 7.41×10^6 GJ, with the assumption of the energy consumed per person in the state is same as that of in the whole country [41]. In other words, the energy produced by TGB can fulfill more than 88% of the energy demand in the state. If algal biomass were fully utilized to produce TGB, liquid bioethanol has the potential to partly substitute fossil fuels through gasohol (gasoline blended with alcohol) blending in vehicles as a renewable source. It means that 35.5% of the country's energy demand can be fulfilled with a cleaner and sustainable renewable energy. The information is arranged accordingly in Table 1.

4. Government policies

To ensure sustainable development and production, policies with great vision have to be formulated. Seeking for highest level of

sustainability, a series of policies have been promulgated by Sabah government such as Sabah Outline Perspective Plan (OPPS), 1995–2010 and Second Agriculture Policy (SAP2). In line with Ninth Malaysia Plan (2006–2010), several programs and projects are launched to assist the private sector especially small holders. According to SAP2, the plans for marine related sectors are:

- Increasing production for food security and exports.
- Improvement in productivity and competitiveness.
- Increasing private sector investment.
- Sustainable exploitation of resources.
- Human resource development.
- Rationalization of fisheries-related institution.

With a long coastline of 1600 km, Sabah has enjoyed marine riches in fishing and aquaculture industry. The state intends to expand the industries by means of sustainable development. Aquaculture would be one of the important sectors to be leveraged. The efforts are translated through technology assistance, expanding infrastructure, support services, enabling of legal framework and investment coordination. The policy is strategically steered to bring equal benefit in joint ventures with the private sector. The government has opened the sector for investment from private sector through business matching programs, especially for large-scale aqua-cultivation. Improvement in automation and mechanization in aquaculture production and product processing has been acknowledged. There are several excellent research facilities for collaborative research along the coastline, particularly in coastal pollution, mangrove ecosystem and marine aquaculture, such as Borneo Marine Research Institute and The Marine Research Foundation. These facilities are financially aided by the government. They play a very important role in research and development of aquaculture industry such as seaweed farming and refining.

At national level, National Energy Policy (1979), National Depletion Policy (1980) and Fuel Diversification Policy (1981, 1999) were formulated to reduce the contribution of oil in the energy mix substantially. Projects such as Small Renewable Energy Power (SREP) Program launched in May 2001 and Biomass Power Generation & Cogeneration Project (BioGen) launched in October 2002 have improved the utilization of renewable energy at industrial scale. In tandem with the federal government to promote renewable energy, refining biomass from aquaculture into fuels is an excellent idea to exalt the state of the industry to link up with the current global economic trend. Production of TGB from algae and seaweeds would be a smart concept for the state since Sabah has great potential in seaweed cultivation. With its unique location surrounded by Sulu Sea and South China Sea, Sabah has the advantage of rich marine biodiversity and suitable climates for growing seaweeds.

5. Challenges and constraints

Although Malaysian government has always emphasized the importance of renewable energy in the energy policies, the results from this matter is still not satisfactory. The failure in meeting the target of 5% blending in biodiesel, known as B5, as stated in National Biofuel Policy epitomizes the muddled planning in the past few years (Ministry of Plantation Industries and Commodities, 2006). According to Ministry of Plantation Industry and Commodities, the volatile market price of palm oil was the major reason for the failure of the policy. For instance, fluctuation of palm oil price in international market has caused insecure raw material supply to biofuel industry. Apart from that, although production of biofuel from non-arable land is attractive, it is still facing a series of difficulties before it can be carried out practically. In this respect, therefore production of TGB from algae would be an interesting alternative for the country as it is more reasonable in terms of risk consideration.

Conversion of polysaccharides in seaweeds into fermentable sugar is still a very new topic. The conventional way of galactan extraction from seaweed involves the employment of alkali treatment by soaking the seaweed in a strong solution of alkali at 70–90 °C up to 5 h [42,43]. However, alkali will reduce the polysaccharide yields [44] and subsequently produce waste stream. In fact, technology for purification of hydrolyzate and fermentation of galactose to ethanol is also not yet developed at industrial scale. It involves a more complicated process compared to fermentation of glucose. Generally, fermentation of galactose requires conversion of galactose into glucose form before ethanol can be produced. The extra step may require more energy input and longer reaction time. Meanwhile, there are still no suitable methods to convert the large amount of 3,6-anhydrogalactose existed in the polysaccharides into ethanol. Fully utilization of this biomass will greatly improve the yield of TGB from seaweeds. Technical limitation might be the largest challenges for algal biorefineries in Malaysia. Genetic engineering may provide the answers but obviously the country is still far behind from biotechnology.

Another hidden worry of seaweed cultivation stems from the pollution of sea water. As a developing country, Malaysia is generating significant amount of waste into the water bodies. Manufacturing industries, agriculture and animal husbandry, agro-based industries and urbanization activities have contributed to the adverse effect on marine environment. As the busiest shipping lanes in the world, the Straits of Malacca receives enormous quantity of waste disposal every day. Without proper management of coastal marine resources, certain coastal area in Malaysia is no longer suitable for aquaculture like seaweed cultivation, especially in the west coast of Peninsular Malaysia. This will not only cause less opportunity for TGB but also influences the fisheries and aquaculture.

However, improper planning is also the key factor to derail the effort to usher the transportation sector on a greener path. Obviously, no proper long-term planning is mooted to decouple the vehicles from oil dependency. Profit driven market tends to impel the users to choose more costeffective source of energy, such as coal and hydroelectricity. Therefore, the country still heavily depends on coal power stations or large hydroelectricity dams [45]. Attempt to transform the energy sphere into a cleaner, sustainable and efficient level have to be pertained to the national long-term development blueprints. At the moment, the investors are less optimistic to the RE sector due to lack of economies of scale. Although pioneer status and investment tax allowances are given to the investors, the incentives do not attract more players to join the industry [46]. In other words, a more comprehensive strategy in aiding the start-up of biofuel plants should be properly marked out, including facilitated bank loans. Besides that, Malaysia is still lacking of necessary infrastructure and facilities.

Up until today, there is no comprehensive blueprint in building up such a biofuel-based transportation system. TGB has its own inherent shortcomings such as hygroscopic and low boiling point. Ethanol-blended fuels like gasohol is unsuitable for ordinary engines due to its hygroscopic properties. During hot weather, it will cause vapor lock in the engines. Transportation and storage of TGB are also facing difficulties for corrosion, dissolution, starting difficulties, and other operating problems. Meanwhile, Malaysia still does not have a long-term planning for biofuel-based transportation system. Flexible fuel vehicles (FFVs) that can operate with high portion of TGB as fuel are still not considered in the future development. To stimulate the growth of TGB industry, a credible FFVs industry must exist as it implies a mature market. However, there are two national car

manufacturers in Malaysia, namely Proton Berhad and Perodua Sdn. Bhd., have the ability to spearhead the development of FFVs in Malaysia in the future.

6. Conclusion

When the energy crisis detonated in the early 21st century, people started to realize that the future circumstances are not unforeseeable. Due to this tendency, policies were changed to eliminate the vulnerability of energy sector. Apart from competition in controlling limited oil resources, adapting credible plans to reduce oil dependency principally with utilization of renewable energy such as SGB and TGB could be pivotal in curbing the issue. To realize a mature and well-developed bioethanol market, it is important to determine the economic feasibility of fuel production. Challenges such as technology insufficiency have to be overcome before a well functioning renewable energy system can be set up. With groundbreaking genetic engineering technologies, modification of macroalgae is attainable to improve its properties and characteristics. Introduction of good strains or cultivation of mixed strains would be one of the methods with advance biotechnology and biochemistry. By discovering and developing new macroalgae species that have increased carbohydrates content, displacement of petroleum-based fuel with seaweed-based bioethanol is not impossible. Considering the great energy demand and availability of suitable sites and manpower in Sabah state, production of TGB from seaweed has a very good perspective. Algal biorefineries shines like a beacon of hope for the development of renewable energy in the state.

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